

# **Optical Properties of Mineral Particles and Their Effect on Remote-Sensing Reflectance in Coastal Waters**

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## **LONG-TERM GOALS**

My long-term goal is to develop the base of knowledge necessary to:

- (i) understand the magnitudes and variability of the optical properties of the ocean;
- (ii) predict the inherent and apparent optical properties of the ocean including remote-sensing reflectance, given the types and concentration of suspended particles;
- (iii) retrieve the inherent optical properties and concentration of optically significant constituents of sea water from reflectance measurements.

## **OBJECTIVES**

The primary objective of this project is to examine the optical properties of mineral particles suspended in seawater. The specific objectives for the reporting period were to measure the absorption properties of mineral particles in the laboratory and to analyze a large data set of absorption measurements taken in various coastal waters.

## **APPROACH**

Because accurate measurements of true absorption by scattering samples such as mineral particles suspended in seawater are extremely difficult, significant efforts focused on absorption measurements under controlled laboratory conditions using special instrumentation. A major source of error in the measurement of absorption by suspended particles is associated with the fact that not all of the scattered light is collected by the absorption meter due to geometry of instrument. In the previous report we described our effort to develop a method for correcting for the scattering error based on 3-D Monte Carlo simulations of radiative transfer within the measurement system. In this reporting period we took another approach. We measured absorption of mineral samples in laboratory with a dual beam spectrophotometer (Perkin-Elmer Lambda 18) equipped with a 15-cm Spectralon integrating sphere (Labsphere). An important attribute of these measurements is that we placed the sample inside the sphere rather than outside the sphere at the entrance port, which was commonly done in the past. This geometry of measurement allowed us to detect light scattered at nearly all angles (with the exception of a small solid angle around the backward scattering angle of  $180^\circ$ ). As a result, we can assume that our measurement provided absorption subjected to very small scattering error, and that no

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correction for this error is needed. This assumption was tested with a  $\text{MgCO}_3$  sample characterized by high scattering and negligible absorption. In addition, the relatively large size of the integrating sphere ensured that the perturbation of the light field within the sphere due to sample cuvette was negligible. This was tested with samples that absorb but do not scatter light. In these tests, the measurements were made with samples placed outside and inside the sphere.

To examine the absorption properties of natural assemblages of marine particles in coastal waters we analyzed a large data set collected during the European project “Coastlooc” (Coastal Surveillance Through Observation of Ocean Color), which took place in various waters around Europe in 1997-98. The study sites included coastal waters in the Mediterranean, Adriatic Sea, English Channel, North Sea, and Baltic Sea. Some sites represented the waters with significant input of terrestrial material from rivers, for example Rhine, Loire, Seine, Thames, Rhone, Po, and Elbe. Data on total particulate absorption, phytoplankton absorption, non-algal absorption, and dissolved organic matter absorption were included in the analysis. One important task of the analysis was focused on the variability in the magnitude, spectral shape, and regional differentiation of absorption by non-algal particles.

Dr. Marcel Babin from France, who has been a visiting scientist in my laboratory since June 2000, played the key role in this work. Dr. Babin was one of the principal investigators of the “Coastlooc” project.

## **WORK COMPLETED**

Laboratory tests of our integrating sphere system for measuring absorption was completed. Measurements of absorption spectra of several samples dominated by mineral particles representative of Saharan dust, Spitsbergen fjords with input of particles from glaciers, and Sea of Japan, were made.

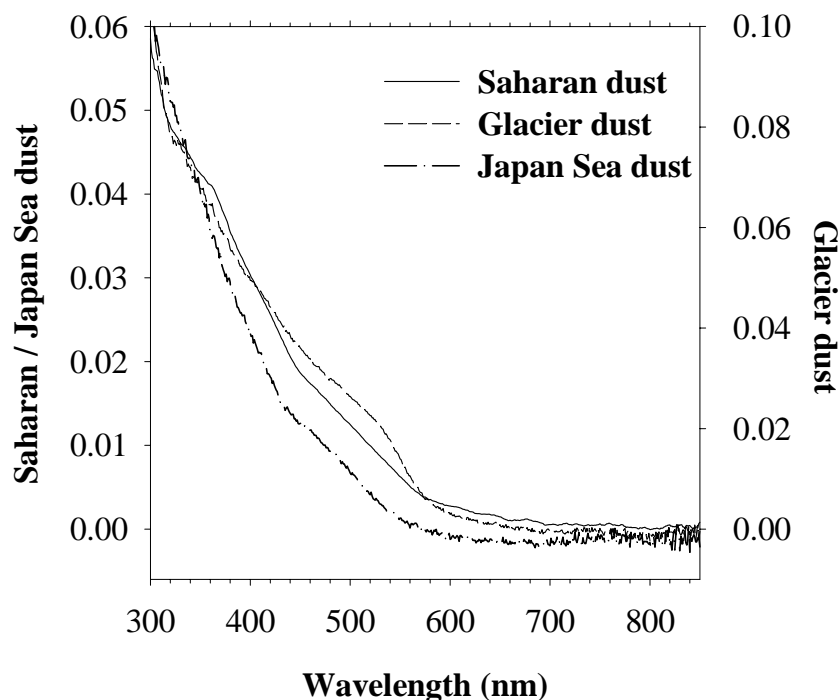
The analysis of Coastlooc absorption data was completed. The manuscript was submitted for publication (Babin et al., submitted).

Two papers resulting from this project were published during the reporting period (Stramski et al., 2001; Loisel et al., 2001). As part of the revision of the paper by Stramski et al., I made a series of new simulations to model the ocean inherent optical properties (IOPs) as a function of the detailed composition of planktonic community. These simulations were focused on blooms of various types of phytoplankton. The other paper (Loisel et al., 2001) compares experimental data with the model for estimating IOPs from apparent optical properties. This model was also developed under this project (Loisel and Stramski, 2000). In addition, I submitted a paper on the effects of growth conditions on phytoplankton optical properties, which is based on my ONR-sponsored research conducted in recent years (Stramski et al., submitted). Finally, two presentations resulting from this project were given at the Ocean Optics XV Conference in Monaco (Stramski and Loisel, 2000; Piskozub and Stramski, 2000).

## **RESULTS**

Tests of our Perkin-Elmer spectrophotometer with the  $\text{MgCO}_3$  samples showed that the scattering error in the absorption measurement is minimal when the sample is placed inside the integrating sphere. Measurements of aqueous solutions of  $\text{K}_2\text{CrO}_4$ ,  $\text{KMnO}_4$ , and  $\text{CuSO}_4$  showed that placing the sample cuvette inside the integrating sphere has negligible effect on the absorption measurement.

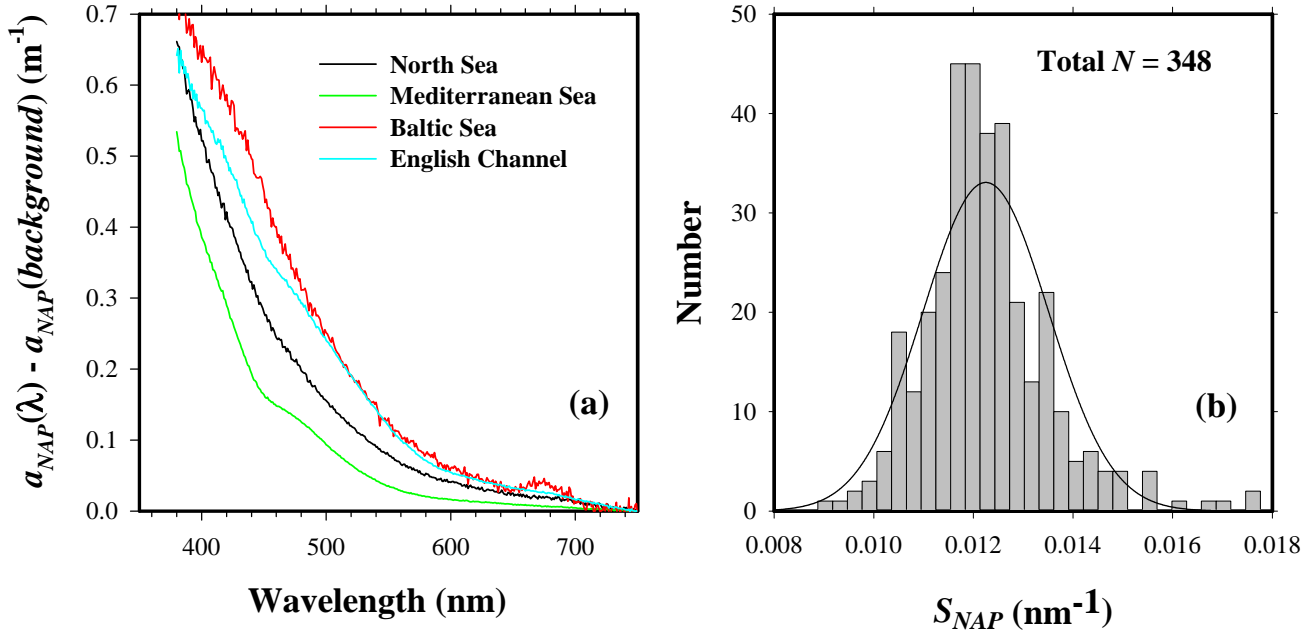
Measurements of absorption spectra of natural samples dominated by mineral particles showed that absorption declines to zero in the near infrared region of the spectrum, 750-800 nm (Figure 1). This is an important result, which does not support scarce data in the literature showing significant absorption in the near infrared. We conclude that previous literature data (e.g., Bukata et al., 1995) are most likely subject to significant scattering error.



**Figure 1. Absorption spectra of natural samples dominated by mineral particles.**  
*[graph: absorption declines to zero as light wavelength increases from the UV to near infrared region of the spectrum]*

Examples of absorption spectra of non-algal particles measured in various coastal waters around Europe during the Coastlooc project are shown in Figure 2 (left-hand panel). For many Coastlooc stations mineral particles make significant contribution to non-algal absorption. In addition to regional differences in the magnitude of non-algal absorption, the spectral shape also shows some variability. Example spectra from coastal waters in the Mediterranean and English Channel show a spectral feature in the 450-500 nm region, that is a noticeable change in the spectral slope. This feature can likely be attributed to clay minerals associated with the presence of iron oxides. The Baltic Sea samples consistently show steeper slope of the spectrum at wavelengths longer than 440 nm compared to the slope at shorter wavelengths. The origin of this feature remains to be an open question. Regardless of this variability, the exponential function provides a good fit to most of our Coastlooc spectra of non-algal absorption. The average value of the exponential slope for all these data is  $0.0123 \text{ nm}^{-1}$  with the coefficient of variation of 10.3% (Figure 2, right-hand panel). The overall range of the slope parameter is from about  $0.009$  to  $0.018 \text{ nm}^{-1}$ . We also found that non-algal absorption shows

significant correlation with dry weight of suspended particulate matter in the investigated coastal waters.



**Figure 2.** *Examples of absorption spectra of non-algal particles in various coastal waters around Europe (left-hand panel) and frequency distribution of the exponential slope of the non-algal particle absorption spectrum based on all the Coastlooc data from European coastal waters (right-hand panel).*

*[graph: absorption spectra of non-algal particles differ in magnitude and spectral shape in various European coastal waters and the average exponential slope of these spectra is  $0.0123 \text{ nm}^{-1}$ ].*

## IMPACT/APPLICATIONS

The major impact of this project is to fill the gap in our understanding of light absorption and scattering by mineral particles suspended in seawater. This understanding is prerequisite to advancing numerous applications associated with optical measurements, especially in coastal environments. Although suspended minerals play a major role in coastal optics (for example, they can often be the most important source of backscattering), these particles have been among the least studied components of sea water. At present, the lack of quantitative information on the optical properties of minerals and their variability limits our capabilities to: (1) understand the magnitudes and variability of the bulk optical properties in coastal waters, (2) develop reliable remote sensing algorithms for coastal waters, (3) develop improved methods for optical imaging/detection of underwater targets and bottom objects, and (4) develop and test shallow water radiative transfer models. I anticipate that this project will contribute to advances in these areas of science and applications.

In addition, potential future impact is to improve models describing the relationships between the ocean optical properties and seawater components. Present models are typically limited only to two or

three components (phytoplankton, detritus, dissolved organic matter) in addition to pure water itself. In this common approach a water body is considered with no regard as to composition of living and non-living particulate matter, for example plankton species or mineral species. This is one important reason for why the present models are unable to explain or predict the substantial optical variability observed in the field. Although a complete optical description incorporating each and every individual component of seawater is clearly unattainable, there is a need to accommodate more components, which would provide a more realistic model. The paper by Stramski et al. (2001) represents a significant step towards the development of such advanced optical models.

## **TRANSITIONS**

Parts of my database of the optical properties of marine particles were made available to Dr. Vladimir Haltrin from Naval Research Laboratory at Stennis Space Center, Dr. Cecile Dupouy from Universite Pierre et Marie Curie in France, and Mr. James Coleman from University of Washington (for his masters work). The entire database have been utilized in radiative transfer simulations carried out by Dr. Curtis Mobley from Sequoia Scientific, Inc.

## **RELATED PROJECTS**

The European project “Coastlooc” (Coastal Surveillance Through Observation of Ocean Color) provided unique data on absorption properties of marine particles in various coastal waters.

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## **PATENTS**

None